

If, again,  $a = \frac{1}{4}$  and  $b = \frac{1}{4}$ , with the other conditions as above, the several temperature increases would be  $2.95^{\circ}\text{C.}$ ,  $1.49^{\circ}\text{C.}$ , and  $26.32^{\circ}\text{C.}$ , respectively.

Apparently, therefore, it is logical enough to attribute the abnormally high temperatures of western and northern Europe of June–August 1783 to the direct greenhouse effect of the relatively coarse volcanic dust from Icelandic volcanoes, Skaptar Jökull especially.

Franklin further states, in the quotation above, not as a surmise, but as an observed fact, that the winter of 1783–84 was abnormally cold. So it was, and so were the 3 years 1784–86 inclusive.<sup>4</sup> However, this widespread low temperature, covering North America, Europe, and northern Asia, or all places where instrumental observations were taken, and presumably, therefore, world-wide, hardly could have been caused by the dust from Skaptar Jökull, or, at any rate, not by its coarser portions, but most likely chiefly, if not well-nigh wholly, by the much higher and far finer dust from Asama in Japan, which exploded violently on August 2, 1783, and more violently still on

August 5, 1783. Dust of this sort and size that in appreciable amounts may remain in the stratosphere even 2, 3, or, possibly, 4 years, depletes passing radiation essentially by diffraction, or scattering, and not mainly by absorption, as do relatively large particles. The theory of this inverse greenhouse effect of fine volcanic dust<sup>5</sup> will not be repeated here as it is rather long and tedious. It shows that the fine dust in question shuts out solar radiation far more effectively than it shuts in earth radiation and therefore causes a greater or less decrease of surface temperatures.

Presumably, then, the summer of 1783 was rendered abnormally warm in western and northern Europe by the then prevailing pall in that region of relatively coarse volcanic dust from Skaptar Jökull, especially; and the following 3 years abnormally cold over much, if not all, of the world by the high, fine dust from Asama.

And it comes to this: Volcanoes, like the man in the fable, can blow hot and blow cold with the same breath, but that shall not provoke us to wrath.

<sup>5</sup> *Physics of the Air*, McGraw-Hill Book Co., 1929.

<sup>4</sup> W. Köppen, *Zeit. Ost. Gesell. für Meteorol.* 8, 200, 1873.

## SHIELDED STORAGE PRECIPITATION GAGES<sup>1</sup>

By J. CECIL ALTER

[Weather Bureau, Salt Lake City, Utah, June 1937]

The gist of nearly two centuries of precipitation gage literature is, that a precipitation gage in any location freely exposed to the upper arch of the sky, will collect a perfect sample of either rain or snow when the air is calm or is moving with only light to moderate velocity, such as are the conditions when much, if not most, of the precipitation occurs.

In the path of a strong wind, however, the precipitation gage, like any other isolated object or structure, becomes a disturbing obstacle, around which, and over the top of which, the immediately adjacent air passes with increased speed. Thus in strong winds the fabric of falling snow is expanded over the gage where the wind runs fastest and the snow pattern is condensed in a spot immediately to the lee of the gage where the wind slows up. As a result, a deficiency of snow is deposited over the gage, and an equal excess is deposited in a similar area a few feet to the leeward. That is to say: During strong winds a small but variable part of the snow rightfully belonging to the gage misses the gage.

The distortion of the sample thus taken, or the deficit in the catch, increases with increased wind velocity; and is from two to four times greater for snow than for rain. The well-known decrease in the catch with increase in elevation of the precipitation gage above ground, results chiefly, it is usually conceded, from the increase in wind velocity in the loftier positions.

For the usual ground exposures where probably 95 per cent of the Weather Bureau gages are exposed, the shrubbery, fences, orchards, shade trees, buildings, and other objects rising on the horizon of the precipitation gage tend to slow up and equalize the speed of the wind over the gage (decrease the range between minimum and maximum velocity). This consequently increases the catch of moisture, and substantially decreases the variability of the catch.

Skyscraper roof exposures so often deprecated as precipitation gage sites are not all bad, for the building itself is often ideally fitted with an overhanging ornamental cornice which substantially prevents the wind stream from rising and racing at increased speed across the roof.

On such a shielded roof a precipitation gage may be placed fairly near the edge, or in any areaway available with reasonable safety to the catch, for the building itself constitutes a huge, shielded precipitation gage.

The user of precipitation data may rest assured, however, that these general defects may nearly all be considered of a minor order or character; because the data, after all, bear a pretty constant ratio to the general precipitation over an area of a few hundred square miles nearest the gage. Thus most precipitation data, despite their well-known defects, are a factor of comparatively dependable constancy among such related variables as evaporation, transpiration, surface run-off, and soil absorption, in hydrologic formulas.

No considerable number of Weather Bureau gages in use are exposed to the full sweep of the wind from any direction, since they are nearly always placed in convenient but sequestered positions on farmsteads or home premises where a certain amount of needful sheltering is always present. Nevertheless, there are usually a few gages in important sections of every State which have inadequate windbreaks, at least in certain quadrants of the gage horizon, and therefore leave the precipitation gage unduly exposed to the certain winds.

Probably a still larger number of gage exposures could be improved if some simple, uniform system of shielding were available, to reduce the variability of the catch in the differing exposures of neighboring gages, and for different velocities and directions of wind over the same gage; that is, if a trustworthy, artificial windbreak could be attached to the gage to give all exposures a semblance of uniform wind eddy control.

A new need for dependable snow gages exists in the unpopulated mountain areas of the West, where there is no one to make daily observations. In these cases the gage must not only effect a reliable collection of perfect samples or falls of snow and rain, in calms as well as in strong winds, but it must preserve this moisture until the gage can be visited and the contents measured (say at the end of the month, since all Weather Bureau data are published in monthly units). Wherever there is a need for a snow survey course, there is a need for at least one sea-

<sup>1</sup> Delivered before the American Meteorological Society at Denver, Colo., June 22, 1937.



FIGURE 1.—Looking southeast, across the experimental plat at Terminal Station, 7 miles west of Salt Lake City, 1936. Four gages with cloth shields in the distance and three with metal-leaf shields in the foreground. No. 1 unshielded check gage is at the extreme left; unshielded check gage no. 9 is just out of view at the extreme right.



FIGURE 2.—Looking northeast. Gage no. 8 in the foreground.

sonal precipitation gage: while an equal or even greater number of such gages are needed on the unpopulated plains areas of the West, for use in studies of forage production, soil erosion, and so forth.

The air that passes with increased speed around the precipitation gage only blows away the snow from the sides of the gage, and does not affect the catch. Thus the thing to be desired, and apparently the only thing that can be done, is to prevent the compression of the air against the gage and the rush of air over the top of the gage by deflecting it downward and away from the receiver or gage mouth. This will leave an unaffected, undistorted movement of air over the top of the gage, comparable to the air movement over the place if the gage were not there.

Nipher did this for rain gages at St. Louis in 1878. He used a trumpet-shaped shield made of sheet metal at the base and wire screen in the upper, wider part of the flare. Marvin designed a shielded snow gage 30 years ago that was nearly perfect for collecting snowfall during strong winds; and it was large enough to preserve several months moisture without emptying. In relatively quiet weather, however, when most snow falls, the wide shelf-like shields, which are set a little above the gage top, collect about as much snow as the gage. The snow, thus piled up on the shield, sometimes to a depth of a foot or more, may thus be blown into the gage receiver, or if solidified by freezing after a slight thaw may vitiate a subsequent catch because of the serious obstruction it offers to the gage receiver.

A common board fence, railing, or guard of almost any kind, placed a few feet from an ordinary gage and about level with the gage top, has been commended by experimentors for years, as tending to increase the amount of the catch and to improve the stability of the catch.

Storage precipitation gages, charged with salt to prevent freezing, and oil to prevent evaporation, have been used regularly with some success in Utah for the past 12 or 15 years. No really serious or unsolvable problem has resulted from the corrosion of gages, and there has apparently been no material loss of moisture due to evaporation, or to the failure of the snow to penetrate the oil film and melt promptly in the brine.

Salt water does not freeze in the ordinary sense of the word; but at low temperatures ice crystals and salt particles separate out, usually in a suspended mass, which does not have the expansive force of ice, does not adhere to the container, and does not float high enough to close the brine surface against further snow receipts. A pound of salt is enough to produce and maintain a high concentration of brine for an 8-inch gage, since the ice crystals always drop out first as the temperature falls. Larger gages need more salt.

Almost any good quality of light oil is satisfactory, though a first-class turbine oil safely undergoes a wide range of temperatures, will endure indefinitely on water without emulsifying or disintegrating, and remains a thin, penetrable film at most snowfall temperatures. About 4 ounces of oil makes a good film, and is sufficient to seal off the brine from the air—the chief source of gage corrosion.

When the 8-inch gage fills within a foot of the top, the contents may be partly or completely emptied as desired; salt is added in proportion, and 2 or 3 ounces of oil will replenish the loss. Measurements are best made by weighing, the gage being exposed without funnel or brass inner tube. A bracket on a portable staff supports the spring-balance scales over the gage, the gage can being lifted with a detachable bail inserted in drill holes at the rim.

Thirty years ago, April 16, 1907, the writer placed 0.20 inch of olive oil on 0.20 inch of water in an 8-inch precipitation gage overflow can covered with funnel receiver but without the inner measuring tube, beside the official 12-inch tipping bucket rain gage at the Salt Lake City Weather Bureau office. On November 3, 1907 the net contents of the storage gage was found to be 7.77 inches or 97 percent of the 8.03 inches that had been measured in the interval in the regular gage.<sup>2</sup> That total happens to be about half the normal annual precipitation at Salt Lake City.

As a result of the above experiment, in the summer of 1910, from April to October inclusive, 10 or 12 improvised storage precipitation gages, using oil films, were exposed by the Utah farmers, on instructions issued from the Salt Lake City office of the Weather Bureau by A. H. Thiessen, then section director. The results were rather gratifying as reported in the MONTHLY WEATHER REVIEW, December 1910, page 1885.

About that time the writer did some experimenting with cloth windshields, and with antifreeze solutions as well as with gages buried, covered, or housed to prevent freezing.<sup>3</sup>

Opportunity again came in the early 1920's for further experimenting, chiefly with salt to prevent freezing. By 1925 this project, developed at the Salt Lake City Weather Bureau office, seemed so practicable, that the three Marvin shielded gages (unmanned in winter) at Alpine, Oak Brush, and Headquarters substations of the Great Basin Forest Service Experiment Station in the mountains near Ephraim, Utah, were charged with brine and paraffin oil for monthly measurement of the increment. This was done with the cooperation of C. L. Forsling, experiment station director, and other Forest Service officials. The records at those stations have been continued, practically to date, with only a few months missing. All data for the 6 winter months for the 12 years past have been obtained by means of the storage gages, using salt and oil.

In 1935, under an allotment of funds by the Weather Bureau, through the River and Flood Division, some more extensive experiments were undertaken in shielding snow gages and storing precipitation. Twenty-seven small cans or containers were exposed on the Weather Bureau office roof at Salt Lake City, to try the resistance of the various metals and combination of metals, and paints and other coverings to the corrosive and galvanic action of salt. Also about as many gages in the field were similarly put on tests.

To date this particular experiment has yielded these apparently justified conclusions: That a copper gage heavily welded with copper welding rod at the folded seams down the side of the gage is practically invulnerable. The bottom seams can usually be covered with a depth of paint or asphaltum or other calking material. A copper fused seam (using no other metal) is too weak and readily develops leaks; stainless steel, Monel, and some other metals are too expensive and are vulnerable at a soldered seam. Even galvanized sheet iron and common tin cans with folded seams well soldered over are trustworthy for some time when oil is used on the brine. But seamless copper or glass gage cans are about the only ones likely to stand up indefinitely because of the galvanic or electrolytic action of the brine against two metals at a gage seam.

We also prepared and exposed about 25 gages fitted with a variety of shields. The principal experimental

<sup>1</sup> MONTHLY WEATHER REVIEW, November 1907, page 511.

<sup>2</sup> See Weather Bureau Circular E, Instrument Division, Measurement of precipitation by C. F. Marvin, 1910, reprinted in 1913, p. 29, also p. 34, par. 96, fig. 7 and par. 81.

plat is at the Utah Power & Light Co.'s Terminal Station, 7 miles west of Salt Lake City, on a wind-swept, water-leveled plain where the average annual precipitation is about 15 inches and snowfall about 50 inches. Most of the 20 gages in this group stand  $3\frac{1}{2}$  feet high and are from 25 to 35 feet apart in orderly arrangement. The gages are standard 8-inch cans, without funnels or inner tubes.

Two gages are 4 feet deep, one being 10.488 inches and the other 14.833 inches in diameter, in which an ounce of water represents 0.02 inch and 0.01 inch respectively. These wide-mouthed gages were provided to observe, if possible, the clinging of wet snow to the top of the gages which sometimes fouls a gage receiver. This difficulty, however, is appreciably lessened by the windshields, which diminish the force of the winds that drive the snow against the top of the gage. The shields also prevent wind eddies from carrying dry snow out of the gages to an appreciable extent.

Four gages are fitted with open skirts or shields made of 8-ounce khaki tenting canvas, cut into wedge-shaped leaves from a band at the top, the whole suspended on a substantial circular iron frame. The lower ends of the 12 pendent leaves, 16 inches long (21 inches on some gages) are strung together on a brass chain in a somewhat smaller circle than the top; and each leaf is stiffened with a single wire rib. The leaves are cut so that the openings between them close up when the leaves are blown in at an angle of about  $45^\circ$ .

Three gages are fitted with shields having diameters of 16, 24, and 34 inches and made of 20-gage galvanized sheet iron, cut into wedge-shaped leaves and suspended on an iron frame, identical with that supporting the canvas shields. These metal leaves are freely hinged on the heavy wire ring at the top and held apart by iron washers. They are connected at the bottom with a brass chain somewhat shorter than the supporting ring. The leaves close up when swung inward at an angle of about  $45^\circ$ . The metal leaves are from 7 to 11 inches in length, on the different sized shields.

Five gages were shielded with combination lath fencing, sawed in two lengthwise. These strips of fencing were hung loosely from a circular support of heavy wire, hooked onto posts set about the gages. The bottom of this swinging "fence" is from 16 to 22 inches above the ground and is flared inward at the bottom by kinking or shortening the lower strand of twisted wires. Being suspended at the top strand of wires 2 inches from the top of the lath, and held in place by small nails in each lath, the bottom of the fence is free to "give" or sway easily with the wind.

Gage no. 10, with a 34-inch lath shield has an extra layer of lath fencing, the lath coming between the original lath, practically closing the "basket" or shield. The other fence shields are from 7 to 12 feet in diameter and the lath from 18 to 24 inches in length, all standing from 1 to 3 inches above the gage tops and clearing the ground by 15 to 20 inches.

Gages number 15 to 18 were arranged to simulate a pit or ground surface exposure, wherein the gage top is flush with the ground level, the gage itself presenting no obstruction to the wind; but in this case we sought to avoid the devastating fault of snow that has fallen, blowing from the ground surface into the gage. That is, at these gages the intention was to arrange a bottom surface of the wind horizontal with the gage top, which would be a surface on which no snow could be deposited, and consequently from which no snow could be blown into the gage.

The tops of these gages are 18 inches high, being sunk 6 inches in the ground. At gage number 16, the smallest possible number of lath and other sticks are carefully spaced in concentric circles and placed so as to prevent any stream of wind from reaching the gage undiverted or undivided. The tops of these sticks are uniformly at a level with the gage top. At gage no. 17, the baffle frames are level with the top of the gage, a few extra baffles being placed to windward. The spaces between the baffle forms are successively wider, counting from the gage. At gage no. 18, the fewest possible number of posts support a 12-by-16-foot area of wire netting, 2-inch mesh, the surface of which is level with the gage top. A wire ring holds the edge of the cut-out 8 inches from the gage. A few additional baffle frames are placed to windward. Access to the gage is gained by hinging a section of the wire netting.

Eight-inch gages, 30 inches deep and mounted from 6 to 12 feet high, fitted with cloth shields like experimental gage no. 6 (34.4 inches diameter, 1 inch above the gage) were exposed at the mountain snowfall stations (beside the official gages) at Clear Creek, 8,300 feet elevation, Kimberly 8,250 feet elevation, and Silver Lake 8,700 feet elevation (half mile distant), and at Salt Lake City 4,300 feet elevation, on a post 6 feet above the instrument platform. An unshielded storage gage was exposed beside the official gage at Salt Lake City; and another unshielded gage at the Highline City Creek station, 5,300 feet elevation, beside the official gage, in a glade or opening among the trees, naturally well sheltered against the wind.

Snowfall observations for 9 months have been made during the past two winters of unusually heavy snow, the experimental gage measurements being divided into six periods or sets of measurements. In order to determine the relative performance of the 18 comparable gages on the experimental plat, the average catch of the full set of gages at each measurement period, was determined and called 100 percent.<sup>4</sup> The percentage relationship of each gage was then computed for comparison. At the end of the sixth or last measurement period in the series, a general summation of all measurements gave a grand average as 100 percent.

The six measurements for each gage separately were also combined and an average percentage relationship determined. Thus it was found that unshielded check gages, numbers one and nine, on opposite sides of the plat, averaged only 85 percent of the 18-gage mean. No. 1 varied from 75 to 99 percent, its mean deviation or variability being 8.2 percent, the worst offender in the lot. The baffled gages, simulating pit exposures, averaged 112.5 percent of the 18-gage series. This may represent more nearly the deposit that would have been made on the plat, had there been no gages to obstruct the wind. Gage no. 17, the middle one with baffles, varied from 105 to 129 percent of the group mean, its mean variability being 7.1 percent.

The three metal shielded gages averaged just 100 percent, the same as the full set of 18. No. 7, with a 24-inch shield, varied from 92 to 106 percent with a mean variability of 3.8 percent, almost exactly the same as no. 4, the smallest metal shield. The 4 cloth shielded gages averaged 95 percent of the 18-gage mean, no. 6 ranging

<sup>4</sup> This method of checking has its faults, but as explained by others, it is about the best system available (see MONTHLY WEATHER REVIEW, July 1915, p. 318. Notes on the effects of rain gage exposures at Berkeley, Calif., by W. G. Reed.)

from 88 to 102 percent, with a mean variability of 3.4 percent. This was the second best performer in point of stability, on the lot.

Four of the lath fence shielded gages averaged 105 percent of the 18-gage mean, the largest one (no. 14) showing the largest average variability of 6.5 percent, ranging from 95 to 120 percent. No. 10, with the double lath shield, had a mean variation of 5.8 percent, ranging from 94 percent to 113 percent. The next best lath shield performer was no. 13, 7½ feet in diameter, with a mean deviation of 5.3 percent, ranging from 95 to 118 percent. While the three gages with metal shields and two with canvas shields are very efficient and promising, an almost neglected "dark horse" wins the sweepstakes, viz, gage no. 11 with the lath-fence shields 34.4 inches in diameter. It had a consistent variability averaging only 1.1 percent, ranging from extremes of only 96 to 100 percent. That is just one-third the average deviation of the second-best gage, and is probably too good to be true for a long series; but as we find nothing wrong with the computation, we must, up to the present, award the first place to the cheapest and simplest of all shields.

We expect to put this shield to further, more severe tests, by changing its position in the set and by mounting it in certain outlandish positions beside official gages elsewhere. It will be given an iron frame mounting similar to that used with the cloth and metal shields, dispensing with the wooden posts that now support it.

The relative efficiency of the several gages on the terminal experimental plot is shown in the following table.

Efficiency rank no.	Gage no.	Description of shield			Average variability	Least catch	Greatest catch	Difference	Average percent of 18-gage mean
		Material	Diameter	Above gage					
1	11	Lath fence.....	Inches 34.4	Inches 1	Percent 1.1	Percent 96	Percent 100	4	98.8
2	6	Canvas.....	34.4	1	3.4	88	102	14	96.7
3	4	Galvanized iron.....	16	1½	3.7	93	102	9	99.3
4	3	Canvas.....	40	6	3.7	85	95	10	91.0
5	7	Galvanized iron.....	24	¾	3.8	92	100	14	98.2
6	8	do.....	34.4	1	4.2	94	108	14	101.2
7	16	Ground baffle.....	75	0	4.7	106	119	13	111.6
8	5	Canvas.....	32	¾	4.8	87	101	19	95.8
9	2	do.....	32	6	4.9	88	101	13	95.3
10	9	None.....			5.1	79	97	18	85.3
11	15	None.....			5.2	93	108	15	98.0
12	13	Lath fence.....	92	2½	5.3	95	118	13	105.0
13	10	do.....	34.4	1	5.8	94	113	19	105.2
14	12	do.....	56	1½	6.0	93	115	22	104.3
15	18	Netting.....	100	0	6.1	106	122	16	112.4
16	14	Lath fence.....	152	4½	6.5	96	120	24	105.5
17	17	Ground baffle.....	84	0	7.1	105	129	24	113.6
18	1	None.....			8.2	75	99	24	84.5

## EXPERIMENTAL STORAGE SNOW GAGE MEASUREMENTS

[Grand totals, in inches, to May 31, 1937]

Station	Official gage measurement	Storage gage measurement	Percent of official gage
High line C. C.....	28.22	29.40 (no shield).....	Percent 104
Silver Lake.....	63.38	55.98 (half mile distant).....	88
Clear Creek.....	26.51	23.90 (sheltered site).....	90
Kimberly.....	28.81	31.01 (windy site).....	108
Salt Lake City.....	28.83	31.46 (lower); 27.77 (higher).....	109 96

## EXPERIMENTAL SHIELDED STORAGE SNOW GAGES AT TERMINAL 7 MILES WEST OF SALT LAKE CITY

## UNSHIELDED CHECK GAGES

Gage nos.	Shields		December 1935	Percent	January 1936	Percent	February 1936	Percent	Oct. 28 and Dec. 1, 1936	Percent	Dec. 1, 1936, and Mar. 27, 1937	Percent	Mar. 27, and May 1, 1937	Percent	Average variation percent	Percent of group average
	Diameter	Height														
1	Inches	Inches	0.70	89	1.63	75	1.25	76	1.24	78	4.93	90	1.29	99	8.2	84.5
9			.66	84	1.73	79	1.38	84	1.25	79	4.86	89	1.26	97	5.1	85.3

## CANVAS SHIELDS

2	32	6	0.77	97	1.92	88	1.66	101							4.9	95.3
3	40	6	.74	94	1.86	85	1.55	95	1.37	86	4.97	91	1.24	95	3.7	91.0
5	32	3½	.79	100	2.05	94	1.74	106	1.39	87	5.07	93	1.24	95	4.8	95.8
6	34.4	1	.81	102	2.08	95	1.62	99	1.40	88	5.36	98	1.27	98	3.4	96.7

## METAL SHIELDS

4	16	1½	0.81	102	2.08	95	1.73	106	1.43	93	5.53	101	1.29	99	3.7	99.3
7	24	¾	.80	101	2.05	94	1.74	108	1.47	92	5.30	97	1.29	99	3.8	98.2
8	34.4	1	.83	105	2.14	98	1.77	108	1.49	94	5.64	103	1.29	99	4.2	101.2

## LATH FENCE SHIELDS

10	34.4	1	0.84	106	2.47	113	1.86	113	1.50	94	5.79	106	1.29	99	5.8	105.2
11	34.4	1	.79	100	2.16	99	1.64	100	1.53	96	5.46	100	1.28	95	1.1	98.8
12	56	1½	.78	99	2.24	103	1.53	93	1.83	115	5.98	110	1.38	106	6.0	104.3
13	92	2½	.79	100	2.27	104	1.55	95	1.87	118	5.88	108	1.36	105	5.3	105.0
14	152	4½	.78	100	2.34	107	1.58	96	1.91	120	5.96	109	1.31	101	6.5	105.5

## GROUND BAFFLES

15	Check gage.....	0.74	94	2.06	94	1.52	93	1.72	108			1.31	101	5.2	98.0
16	Baffles.....	.85	108	2.59	119	1.78	109	1.84	116			1.38	106	4.7	111.6
17	do.....	.85	108	2.81	129	1.80	110	1.85	116			1.36	105	7.1	113.6
18	Netting.....	.86	109	2.67	122	1.75	107	1.88	118			1.38	106	6.1	112.4
	Average variability.....		4.7		11.2		7.5		12.2			6.1		3.2	
19	Gage diameter 10.488 inches.....									5.64	103	1.24	95		
20	Gage diameter 14.833 inches.....											6.82			
	Means.....	.79		2.18		1.64		1.59		5.46		1.30			
	Average wind m. p. h. on stormy days.....	5.7		7.0		8.1		6.4		7.9		9.9			